Technical Paper

EVALUATION OF FACTORS INFLUENCING DRIVEWAY ACCIDENTS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

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FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Attached is a Technical Paper titled "Evaluation of Factors Influencing Driveway Accidents" which has been accepted for presentation at the January, 1976 meeting of the Transportation Research Board in Washington, D. C. The paper has been authored by Messrs. W. W. McGuirk and G. T. Satterly, Jr. The paper is a summary of the important findings of the Final Report from the research study of the same title, JHRP Report No. 10, May 1973.

The paper may be published by the TRB and approval to offer for such publication is therefore requested.

Respectfully submitted,

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Abstract

Full control of access is obviously not the solution to the problem of lowering the number of accidents that occur on our urban arterial highways. We must accept the fact that both land access and traffic movement must be allowed on this type of facility, identify the causes of resulting traffic accidents, and act accordingly to correct deficiencies. The literature abounds with facts concerning intersectional accidents, but relatively little has been written to identify the major contributors to driveway-related traffic accidents, which this research has revealed to account for almost 14% of the total arterial highway traffic accidents.

This research project sought to identify some of the characteristics of driveway accidents and to relate driveway accident occurrence to various physical and environmental features of the roadway and traffic characteristics. Through statistical analysis it was shown that the driveway accident rate tends

to decrease as the spacing between two driveways and as the spacing between a driveway and an adjacent intersection increases. Multiple regression analysis was used to develop a series of mathematical models relating the driveway accident rate to the roadway's physical and environmental features and traffic characteristics. This procedure revealed the driveway accident rate to decrease if the number of commercial driveways per mile is decreased, if the number of through-traffic lanes is decreased, if the number of total intersections per mile is increased, if the number of total driveways per mile is decreased, or if the arterial highway ADT is decreased.

The results of this study provide the engineer or public official with the tools enabling him to better identify the circumstances related to driveway accidents, to predict driveway accidents rates, and to estimate the effectiveness of measures he employs to reduce such accidents.

INTRODUCTION

The reduction of traffic accidents throughout the world is, and always will continue to be, one of the primary objectives of the highway engineer. His quest for this goal was substantially realized with the introduction of the concept of full control of access, which has been hailed as the most significant factor in accident reduction developed thus far. However, full control of access cannot be employed as a sole solution to the problem of accident reduction because a complete highway system must provide the functions of both land access and traffic movement. The problem of accident reduction is further complicated on those facilities where these two functions must be simultaneously coordinated without delegating an advantage to either. A case in point is the urban arterial highway which, by nature of its role in the urban transportation system, must encourage efficient through-traffic movement while providing access possibilities for abutting landowners.

Access to the arterial highway is accomplished by means of driveways, each of which introduces an additional conflict to the through traffic. As the number of such conflict points along an arterial highway increases, the opportunity for driveway-related traffic accidents increases. A driveway accident is defined as a traffic accident in which at least one of the participants was involved in a movement to or from a driveway at the time of the accident, or an accident resulting from such a movement.

The reduction in number of a particular type of accident on an arterial highway can only be effected after the major factors contributing to its occurrence can be identified. The literature abounds with studies which have succeeded mathematically in identifying such factors as they relate to accidents at intersections, but relatively little has been written to identify the major contributors to driveway accidents. Driveway accidents do represent a significant

percentage of total arterial highway traffic accidents, as evidenced by a recent study made in Skokie, Illinois, which revealed driveway accidents to represent 12% of that city's major street accidents. (1) Since there is little reason to doubt that this figure is representative of urban arterial highway accident experience throughout the country, research directed toward a better understanding of the factors affecting the number of driveway accidents on urban arterial highways would be of great benefit.

PURPOSE

This research was developed to provide a means for improving overall highway safety, and to expand upon the limited existing driveway accident facts available to engineers and other public officials. A literature search disclosed numerous voids and some conflicts of opinion on the subjects of driveways and driveway accidents. (2) These observations were used to develop the following objectives of this research:

1. Develop and evaluate characteristics of driveway accidents;
2. Relate driveway accident rates to the average spacing over a section of roadway between adjacent driveways;
3. Relate driveway accident rates to the average spacing over a section of roadway between a driveway and an adjacent intersection leg;
4. Relate driveway accident rates to characteristics of the roadway and its abutting environment and to traffic characteristics.

DATA COLLECTION TECHNIQUES

The procedure followed in this study was to analyze relevant data obtained from one hundred sections of urban arterial highway. Ten roadway sections were taken from each of ten central Indiana cities whose population exceeded

30,000 people. Three specific types of roadway data were recognized as necessary in the analyses: physical roadway data, traffic volume data, and traffic accident data.

Data pertaining to roadway characteristics were obtained by traveling to each site and inventorying all existing physical features of each roadway. A measuring wheel was used on both sides of every section to obtain an accurate measurement of all access and intersection spacing details. However, because many factors could conceivably influence the driveway accident rate, homogeneity with respect to certain variables throughout the length of each study section was mandatory. Therefore, before any section was selected for study, the following criteria were evaluated as met:

1. Curb parking characteristics must remain constant.
2. Curb to curb street width must remain constant.
3. No type of median divider can be present.
4. No major changes in traffic volume may occur between the termini of each section.
5. No major construction must have occurred on the section or on land abutting the section later than one year prior to the beginning of the study (1968).
6. Each section selected for study must be located outside the limits of the central business district but within the city limits.

Driveway types were classified into four different categories - residential, commercial, industrial, and other. The first three classes refer to the principal land use served by the driveway while the fourth includes driveways to land uses which could not be placed in the first three categories, such as fire houses, schools, and churches.

Most of the traffic volume data were obtained from state and local highway and planning officials. However, 19% of the data which could not be obtained through these channels had to be secured by placing traffic counters at representative locations within each section. In all cases, however, by using the pertinent traffic volume expansion factors and by assuming a 4% annual increase in traffic volume, the average daily traffic volume (ADT) for each roadway section was obtained for each required study year.

Traffic accident data were collected for each of the 100 roadway sections for the period from January 1, 1968, to December 31, 1971, from the standard accident report form as filed by the investigating police officer. Pertinent driveway accident data were transferred from the report to a pre-prepared form, with one being prepared for each driveway accident.

The methods of analysis determined how the data would be refined for study. Analysis satisfying the first objective of this study, the identification of driveway accident characteristics, required the entire four year accident history of each roadway section. No special treatment of the data was necessary. The study of the next three objectives, however, required the development of accident rates which could be mathematically related in multiple regression analysis to particular characteristics of the study sections. Two accident rates, accidents per mile per year and accidents per 100 million vehicle miles, were developed; although the latter rate was discarded early in the analysis due to its inability to relate as well to the roadway characteristics as did the accidents per mile per year. A three year annual average of the 1968-1970 accident data was used to develop the accident rates used in multiple regression analysis. In order to test the hypothesis that the three years of accident data originated from the same population, the chi-square goodness-of-fit test was applied to data from each of the one hundred sections. When all but eight

of the sections passed the test, and when it was determined in initial analyses that more statistically reliable results could be obtained without those eight sections, only 92 roadway sections were selected for analysis and used for the latter three study objectives. The 1971 accident data were used to develop the accident rates used in testing the resulting regression equations.

ANALYSIS OF DATA

Driveway Accident Characteristics

Characteristics Based Upon All 100 Roadway Sections:

The four-year accident history of 100 central Indiana urban arterial highway sections totaling 60.436 miles in length revealed a total of 1212 driveway accidents. This represented 13.95% of all reported traffic accidents on these same roadway sections.

The following results were obtained when similar characteristics of each of the 1212 driveway accidents were grouped together:

1. The fewest number of driveway accidents occurred on Sunday when traffic volumes are lowest and when most business establishments are closed; while a higher number was experienced on Friday and Saturday when traffic volumes are heavier and when more trips to commercial establishments, on the average, occur. The following figures indicate the number of driveway accidents and the percent of the total number of driveway accidents that occurred each day.

Sunday	92	7.59%
Monday	166	13.70%
Tuesday	146	12.05%
Wednesday	132	10.89%
Thursday	188	15.51%
Friday	255	21.04%
Saturday	233	19.22%

2. 71.62% of all driveway accidents involved a maneuver into or from a commercial establishment.

3. 85.56% of the driveway accidents resulted in property damage only while the remainder involved personal injury. None of the reported accidents resulted in a fatality.

4. Vehicles turning left into or from driveways were involved in 64.60% of all driveway accidents. 76.00% of all driveway accidents resulting in personal injury involved a left turn maneuver.

5. 53.47% of the driveway accidents involved a vehicle entering a driveway while the remainder involved an exit maneuver.

6. 60.07% of the driveway accidents were of the right angle variety, while 33.09% involved a rear-end collision. A majority of the rear-end collisions were the result of the driveway vehicle being struck while waiting to turn into a driveway.

7. Driveway vehicles were struck by through-traffic vehicles in 57.01% of the cases, whereas they struck the through-traffic vehicles in 33.34% of the cases. The driveway vehicle was not directly involved in the actual collision in the remainder of the driveway accidents studied.

8. 72.28% of all driveway accidents occurred during daylight hours when traffic volume is heaviest.

9. 75.00% of the driveway accidents occurred during periods of non-precipitation and 70.05% occurred under dry pavement conditions. These results probably reflect the lower number of inclement weather days that occur in a year.

Characteristics Based Upon Significant Data Splits:

In this analysis, the data was split into two or more logical categories, with observations as to corresponding differences between the groups being made.

Three data splits were recognized as significant and analyzed in this phase of the study.

The sample consisted of 29 one-way streets and 71 two-way streets. As indicated in Table 1, over a four-year period, two-way streets experienced, on the average, almost 2.75 times the number of driveway accidents per mile as did one-way streets. However, associated with this statistic is the fact that the one-way streets in this sample had a lower ADT and fewer commercial driveways per mile, both of which may explain this difference.

The entire sample of 100 arterial street sections had from one lane to four lanes. As evidenced in Table 2, an increase in the number of through-traffic lanes was, on the average, accompanied by increases in the number of driveway accidents per mile, the number of commercial driveways per mile and the ADT, indicating that different combinations of these variables could have a significant effect upon the driveway accident rate.

While a consistent relationship does not occur, there is a definite trend toward more driveway accidents per mile and more commercial driveways per mile in higher ADT ranges, as indicated in Table 3. The ADT ranges into which the sections were categorized were determined by plotting the number of driveway accidents per mile against ADT, and selecting definite clusters of points as intervals.

Driveway Spacing Analysis

The literature recommends longer distances between adjacent driveways and between driveways and adjacent intersection legs, but these conclusions are based upon criteria other than the driveway accident rate. In an attempt to determine the relationships between driveway spacing and the driveway accident rate, scaled maps were reproduced for each of the 92 significant roadway sections from the measurements obtained in the earlier field inventories. Two average driveway spacing variables were developed for each roadway section. The average spacing

TABLE 1

Driveway Accident Characteristics

One-Way Streets vs. Two-Way Streets (4 Year Period)

	One-Way Streets	Two-Way Streets
Number of Roadway Sections	29	71
Driveway Accidents Per Mile	23.843	8.761
Driveway Accidents as Percentage of Total Accidents	6.37%	16.35%
Average ADT	7582 VPD	9905 VPD
Commercial Driveways Per Mile	16.20	21.32

TABLE 2

Driveway Accidents Per Mile, Commercial Driveways Per Mile, and ADT as a Function of the Number of Through-Traffic Lanes in Both Directions (4 Year Period)

Number of Lanes	Number of Section Samples	Driveway Accidents Per Mile	Commercial Driveways Per Mile	ADT
1	3	1.378	7.581	1713
2	74	12.011	15.777	7843
3	5	15.272	28.115	11648
4	18	51.194	34.395	15522

TABLE 3

Driveway Accidents Per Mile and Commercial

Driveways Per Mile as a Function of ADT (4 Year Period)

ADT Range	Total Number of Section Samples	Number of Sections in Sample Containing "x" Lanes				Driveway Accidents Per Mile	Commercial Driveways Per Mile
		x = 1	x = 2	x = 3	x = 4		
0-5000	22	3	19	0	0	3.944	4.970
5001-6800	16	0	15	1	0	7.051	15.226
6801-8800	17	0	15	1	1	13.432	16.906
8801-10200	7	0	7	0	0	11.644	13.470
10201-11900	8	0	5	1	2	17.666	17.854
11901-14600	13	0	6	1	6	32.388	24.714
Over 14600	17	0	7	1	9	48.837	42.592

between two adjacent driveways was defined as the sum of the centerline to centerline distances between two adjacent driveways divided by the number of times in a section two driveways appeared next to each other. Likewise, the average spacing between a driveway and an adjacent intersection leg was defined as the sum of the centerline to centerline distances between a driveway and an adjacent intersection leg divided by the number of times in each section that a driveway appeared adjacent to an intersection leg. Both average spacing variables were developed by considering driveways on both sides of the street.

The technique of analysis was to plot each average spacing variable against the corresponding number of driveway accidents per mile per year for each section. Since both plots displayed such a scatter of points that useful, significant information could not be obtained, it was decided to fit the best possible straight line through the points by utilizing the technique of least squares. Designating Y as the number of driveway accidents per mile per year, X_1 as the average spacing over a section of roadway between adjacent driveways, and X_2 as the average spacing over a section of roadway between a driveway and an adjacent intersection leg, the following two regression equations were developed:

$$Y = 7.728 - 0.055X_1$$

$$Y = 11.584 - 0.068\, X_2$$

The correlation between Y and X_1 was -0.166, and the correlation between Y and X_2 was -0.318, indicating that neither of the two driveway spacing variables are related linearly to the annual number of driveway accidents per mile. However, the negative sign preceeding the coefficients of the independent variables and the negative sign preceeding each of the correlation coefficients suggest a trend toward lower driveway accident rates as driveways are located further from other driveways and/or intersection legs. One should keep in mind, however, that an increase in either spacing variable implies a decrease in the number of driveways on a section of roadway. This would surely contribute to a decrease in the driveway accident rate.

Relationship Between Driveway Accidents, Roadway Characteristics and Traffic Volume Characteristics

Analysis Technique:

One method for establishing which factors, and their relative order of importance, have the greatest effect upon the driveway accident rate is stepwise linear regression analysis. This statistical technique involves the defining of a dependent variable, the number of driveway accidents per mile per year, and a number of independent variables which are suspected to have an influence in the dependent variable. This analysis considered a total of 26 independent variables representing what was felt to be the 24 most important and most logical roadway, environmental and traffic volume factors. Because stepwise multiple regression analysis works by scanning an array of independent variables and choosing in succession those most closely related to the dependent variable, it was believed advantageous to provide as many independent variables as possible. A listing of the independent and dependent variables, as they were coded for computer analysis, is presented in Table 4.

Stepwise multiple regression analysis was used to develop equations for eight different combinations of the study sections. One regression equation was developed for each of the following categories: all 92 study sections, all one-way street sections, all two-way street sections, and all two lane street sections. The remaining four equations were developed using the same categories of data with the sections from Indianapolis removed from each. This was done to test the effect of urban area population on the driveway accident rate, as nine of the urban areas had populations between 30,000 and 80,000 people, while the population of Indianapolis was 750,000 people.

TABLE 4

List of Variables

Index	Variable Description
Y	Driveway Accidents Per Mile Per Year
X_1	1970 Urban Area Population in Hundred Thousands
X_2	1969 Average Daily Traffic Volume in Hundred Thousands
X_3	Street Type
	$X_3 = 0$ One-Way Street
	$X_3 = 1$ Two-Way Street
X_4	Roadway Section Speed Limit (MPH)
X_5	Curb to Curb Street Width (ft.)
X_6	Number of Through-Traffic Lanes
X_7	Lane Markings
	$X_7 = 0$ No Lane Markings
	$X_7 = 1$ Lane Markings Visible
X_8	Number of Stop Signs and Red Flashing Traffic Signals Per Mile
X_9	Number of Traffic Signals Per Mile
X_{10}	Number of Yield Signs and Yellow Flashing Traffic Signals Per Mile
X_{11}	Number of 3-Way Intersections Per Mile
X_{12}	Number of 4-Way Intersections Per Mile
X_{13}	Number of Total Intersections Per Mile
X_{14}	Number of Alleys Per Mile
X_{15}	Number of Residential Driveways Per Mile
X_{16}	Number of Commercial Driveways Per Mile
X_{17}	Number of Industrial Driveways Per Mile
X_{18}	Number of Other Driveways Per Mile

TABLE 4 (Continued)

List of Variables

Index	Variable Description
X_{19}	Number of Total Driveways Per Mile
X_{20}	Number of Friction Points Per Mile
X_{21}	Average Spacing Between Adjacent Driveways (ft.)
X_{22}	Average Spacing Between Driveways and Adjacent Intersection Legs (ft.)
X_{23}	Curb Parking Restrictions Denoted as Follows:
X_{24}	

X_{23}	X_{24}	
0	0	No Parking Both Sides of Street
1	0	Parking One Side of Street Only
0	1	Parking Both Sides of Street

Index	Variable Description
X_{25}	Curb Condition Denoted as Follows:
X_{26}	

X_{25}	X_{26}	
0	0	No Curbs Both Sides of Street
1	0	Curbs One Side of Street Only
0	1	Curbs Both Sides of Street

The eight regression equations were developed in a three-step process. The first step involved subjecting the data to stepwise regression analysis. Only linear independent variables which effected a significant increase in the multiple correlation coefficient (R^2) were permitted to enter the equation. The second step again employed stepwise multiple linear regression with the independent variables being all of the significant linear terms from the first step and all possible two-way products of these linear terms. These two-way products represent interactions between two independent variables, and these products proved in every case to be more significant than the sum of their component variables. Once again, only those terms which contributed a significant increase to the multiple correlation coefficient were permitted to enter the equation. Since a model which contains interaction terms must also contain the main effect terms which comprise the interaction, and since in some cases one or more of the main effect terms were not significant enough to enter the equation in the second step, the third step was introduced to force these main effect terms into the final equations.

The Eight Regression Equations:

Eight regression equations relating the driveway accident rate to significant roadway and environmental characteristics were developed. They are as follows:

1 - Using data from all 92 study sections

$$
\begin{aligned}
Y = {} & -7.067 + 0.300(X_1) + 15.550(X_2) + 2.250(X_6) + 0.636(X_{13}) \\
& + 0.075(X_{16}) + 0.024(X_{19}) + 0.024(X_6)(X_{16}) - 0.372(X_6)(X_{13}) \\
& + 0.280(X_2)(X_{19}) - 0.009(X_1)(X_{19}) - 0.010(X_{13})(X_{16}) \\
& + 0.067(X_1)(X_{13}) \qquad [R^2 = 0.85]
\end{aligned}
$$

Where: Y = Driveway accidents per mile per year

X_1 = Urban area population/100,000

X_2 = 1969 ADT/100,000

X_6 = Number of through-traffic lanes

X_{13} = Total intersections per mile

X_{16} = Commercial Driveways per mile

X_{19} = Total Driveways per mile

2 - Using data from all 92 study sections except Indianapolis

$$Y = +\,0.130 - 4.583(X_2) - 0.494(X_6) + 0.764(X_{13}) + 0.178(X_{16}) - 0.130(X_{20}) + 0.079(X_2)(X_{16}) - 0.009(X_{13})(X_{16}) + 0.082(X_6)(X_{20}) + 320.927(X_2)^2 - 0.448(X_6)(X_{13}) \qquad [R^2 = 0.86)$$

Where: X_{20} = Friction points per mile

3 - Using data from all two-lane study sections

$$Y = +\,0.170 + 0.010(X_1) + 20.034(X_2) + 0.014(X_{13}) + 0.111(X_{16}) + 1.413(X_2)(X_{16}) - 0.011(X_{13})(X_{16}) - 0.030(X_1)(X_{16}) \qquad [R^2 = 0.71]$$

4 - Using data from all two-lane study sections except Indianapolis

$$Y = -\,2.211 + 69.795(X_2) + 0.191(X_{13}) + 0.021(X_{14}) + 0.026(X_{16}) + 1.609(X_2)(X_{16}) - 0.009(X_{13})(X_{16}) + 0.003(X_{14})(X_{16}) - 3.978(X_2)(X_{13}) \qquad [R^2 = 0.78]$$

Where: X_{14} = Alleys per mile

5 - Using data from all one-way street study sections

$$Y = -1.592 + 8.996(X_2) + 0.179(X_{18}) - 0.006(X_{19}) + 0.970(X_{24})$$
$$+ 1.096(X_2)(X_{19}) - 32.035(X_2)(X_{24}) \qquad [R^2 = 0.86]$$

Where: X_{18} = Other driveways per mile

X_{24} = 1 Parking permitted on both sides of street

0 Parking not permitted or is permitted on one side of the street only

6 - Using data from all one-way street study sections except Indianapolis

$$Y = -2.333 + 25.728(X_2) - 0.428(X_7) + 0.378(X_{13}) + 0.031(X_{19})$$
$$+ 1.020(X_2)(X_{19}) - 0.032(X_{13})^2 - 0.028(X_7)(X_{19}) \qquad [R^2 = 0.87]$$

Where: X_7 = 1 Lane markings are visible

0 No lane markings

7 - Using data from all two-way street study sections

$$Y = +21.425 + 0.041(X_1) - 11.070(X_6) + 0.216(X_9) - 0.378(X_{13})$$
$$+ 0.043(X_{16}) - 0.041(X_{17}) - 0.053(X_{21}) + 0.060(X_6)(X_{16})$$
$$- 0.001(X_{13})(X_{21}) - 0.015(X_{16})(X_{17}) - 1.379(X_6)(X_9) - 0.022(X_1)(X_{16})$$
$$+ 0.019(X_9)(X_{21}) + 2.475(X_6)^2 + 0.119(X_9)(X_{13}) + 0.029(X_9)(X_{16})$$
$$[R^2 = 0.84]$$

Where: X_9 = Traffic signals per mile

X_{17} = Industrial driveways per mile

X_{21} = Average spacing over a section of highway between adjacent driveways (feet)

8 - Using data from all two-way street study sections except Indianapolis

$$Y = + 0.098 + 23.967(X_2) + 1.513(X_6) + 0.225(X_{13}) + 0.167(X_{16}) - 0.004(X_{21}) + 0.995(X_2)(X_{16}) - 0.016(X_{13})(X_{16}) + 0.014(X_6)(X_{16}) - 0.010(X_{13})(X_{21}) \qquad [R^2 = 0.82]$$

Evaluating the Regression Equations:

The most obvious feature of these eight regression equations is their relatively high multiple correlation coefficients. While it is not apparent in this presentation, it is noteworthy to point out that the introduction of cross products into the models added considerably to the numerical value of R^2.

Without a doubt, the variable having the most significant effect upon the driveway accident rate was the number of commercial driveways per mile. Only in the one-way street analysis did this variable prove to be insignificant. This is probably due to the low number of one-way streets and the lack of substantial commercial development fronting those one-way street sections used in this analysis. Further computations using the models indicated that each commercial driveway to an arterial street adds between 0.1 and 0.5 driveway accidents per mile per year, the actual figure depending primarily on the ADT and the number of traffic lanes on the arterial. Other independent variables which seem to have an important effect upon the driveway accident rate are the number of through-traffic lanes, the arterial highway ADT, and the number of total intersections per mile. Computations revealing the mathematical sign preceeding each of these significant variables indicated that the driveway accident rate will increase if the number of commercial driveways per mile is increased, if the urban arterial ADT increases, if the number of traffic lanes is increased, and if the number of total intersections

per mile decreases. Only minor deviations attributable to variable interactions were evident in the analysis. These results are not only inherent from the models, but exactly as one would expect in a real situation. It is significant to note that the number of residential driveways per mile is related in no way to the driveway accident rate.

The effect of urban area population was significant. This variable entered the regression equation as a moderately significant predictor of the dependent variable when the Indianapolis sections were included in the analysis, but it had no significance whatsoever when these sections were omitted from the analysis. In addition, in most cases, the arterial highway ADT was found to take on additional significance as an independent variable when the Indianapolis sections were not included in the analysis.

One of the major findings of this study was the degree of superiority exhibited by the product of two independent variables over the sum of the same two variables as a predictor of the dependent variable. These products represent interactions between variables, and their possible use in this analysis was first brought to light during the discussion on driveway accident characteristics. The two most significant interactions in this study were that between the number of through-traffic lanes and the number of commercial driveways per mile, and that between the ADT and the number of commercial driveways per mile. In the first case, more commercial driveways per mile are generally found on highways with more traffic lanes. As both of these variables increase in numerical value, so does the driveway accident rate, on the average. The same analogy can be found in the second case. This is to say that the two variables seem to increase or decrease in value at approximately the same rate as the dependent variable; thus the interaction, represented by the product of the two terms.

At first glance, any one of the eight equations may seem difficult to use. However, an engineer can quickly determine the driveway accident rate of a particular stretch of roadway by knowing a maximum of only seven (7) roadway factors and applying them in proper sequence in the appropriate regression equation. Each equation should produce reasonably reliable results, as long as the data entered into the equation is within the range of the data used to develop each. The range of each variable, however, varies in each of the eight equations because of the different source of data from which each was developed. For purposes of comparison and general information, the ranges of significant variables associated with Equation Number 1, which was developed from the data of all 92 roadway sections, and with Equation Number 7, which was developed from the data of all 64 two-way street sections, are presented in Table 5 and Table 6 respectively. Table 5 also indicates the range of all other variables that were significant in at least one of the other equations. In most cases, as is evident by comparing the two tables, the range of a certain variable in a given equation will be less than that presented in Table 5. Along with the ability to provide a reasonable estimate of the driveway accident rate on a particular segment of undivided arterial highway, these equations can be used by the engineer to indicate how much of a change is required in one or more roadway characteristics to effect a desired change in the driveway accident rate.

Testing the Models:

The eight models were tested by using each to predict the annual number of driveway accidents per mile that would occur on a particular study section in 1971 and comparing those results with the actual 1971 driveway accident rate. These two figures were compiled for each study section, and the individual differences between the actual and the predicted driveway accident rates were used to develop a multiple correlation coefficient.

TABLE 5

Range of Significant Variables (Equation Number 1)

Sample Size = 92

Variable	Index	Maximum	Minimum	Range
Driveway Accidents/Mile/Year	Y	28.4	0	28.4
Urban Area Population	100000(X_1)	744624	31403	713221
ADT	100000(X_2)	31034	1153	29881
Number of Traffic Lanes	X_6	4	1	3
Lane Markings	X_7	1	0	0
Traffic Signals/Mile	X_9	11.7	0	11.7
Total Intersections/Mile	X_{13}	23.6	2.7	20.9
Alleys/Mile	X_{14}	35.3	0	35.3
Commercial Driveways/Mile	X_{16}	73.3	0	73.3
Industrial Driveways/Mile	X_{17}	26.8	0	26.8
Other Driveways/Mile	X_{18}	21.9	0	21.9
Total Driveways/Mile	X_{19}	119.3	25.9	93.4
Friction Points/Mile	X_{20}	130.4	35.4	95
Driveway-Driveway Spacing	X_{21}	133.3	25.2	108.1
Parking	X_{24}	1	0	1

TABLE 6

Range of Significant Variables (Equation Number 7)

Sample Size = 64

Variable	Index	Maximum	Minimum	Range
Driveway Accidents/Mile/Year	Y	28.4	0	28.4
Urban Area Population	$100000(X_1)$	744624	31403	713221
Number of Traffic Lanes	X_6	4	2	2
Traffic Signals/Mile	X_9	8	0	8
Total Intersections/Mile	X_{13}	20.7	2.7	18
Commercial Driveways/Mile	X_{16}	73.3	0	73.3
Industrial Driveways/Mile	X_{17}	26.8	0	26.8
Driveway-Driveway Spacing	X_{21}	131.6	28.5	103.1

When these eight multiple correlation coefficients were compared to those associated with each respective model, differences were obvious and excessive. In addition, the differences between the actual and predicted driveway accident rates indicated extreme variance. For example, the regression equation developed on the basis of data from all 92 study sections explains 85% of the variation of the averaged 1968-1970 driveway accident rate, but this same equation could explain only 53% of the variation in the 1971 driveway accident rate. Likewise, the accompanying residuals ranged in value from 19.8 to -13.4 for a range of 33.2.

The results are not an indication of unreliability in the predictive capacities of the models. Rather they emphasize the importance of the major controls incorporated throughout this study. In all cases, models developed on the basis of the annual average of a three year accident history (1968-1970) were used to predict a one year accident history. It is possible, in some cases, that the number of 1971 driveway accidents per mile for a given section does not agree statistically with its corresponding 1968-1970 averaged number of driveway accidents per mile. In fact, preliminary computations indicated a higher value of R^2 and a smaller range of residuals when sections featuring obvious discrepancies between the two driveway accident rates were omitted from this phase of the analysis. It is obvious from the study that the models will predict a three year annual average driveway accident rate and not a driveway accident rate based upon a one year accident history.

CONCLUSIONS

The following conclusions concerning driveways and driveway accidents on urban arterial highways in central Indiana are presented.

1. Driveway accidents represent a significant percentage of the total traffic accident experience on urban arterial highways, and steps taken to effect their decrease would bring about an improvement in overall highway safety.

2. Public officials should consider measures such as barrier medians, traffic signals, left turn lanes and left turn prohibitions at certain driveways as a means toward effecting a reduction in driveway accidents and in personal injuries resulting from such accidents.

3. There exist trends in which the driveway accident rate decreases when the average spacing over a section of arterial highway between adjacent driveways and between a driveway and an adjacent intersection leg increases.

4. Certain roadway and environmental factors and traffic volume characteristics can be used to predict the annual number of driveway accidents per mile significantly better than they can predict the number of driveway accidents per 100 million vehicle miles.

5. The interaction, or product, of two variables proved to be more significant, in every case, than the sum of the same two variables when predicting the number of driveway accidents per mile per year.

6. Driveway accident rates based upon the annual average of a three year accident history produce better results in regression analysis when it can be shown that the three separate years of accidents used to derive the rates originated from the same population.

7. The number of driveway accidents per mile per year will decrease when one or more of the following conditions occur:

a. the number of commercial driveways per mile is reduced;

b. the number of through-traffic lanes is reduced;

c. the number of total intersections per mile is increased;

d. the number of total driveways per mile is reduced;

e. the arterial highway ADT is reduced.

Other factors were shown to have a less pronounced effect upon the driveway accident rate.

8. Urban area population can be employed as a significant predictor of the number of driveway accidents per mile per year when the study samples are derived from urban centers whose population differences are significantly large. However, the effectiveness of this variable as a predictor decreases rapidly as this difference becomes less pronounced. This may be due to the fact that motorists from larger cities are more accustomed to traveling upon urban arterial highways.

9. Mathematical models describing the driveway accident rate on one-way streets, two-way streets, and two-lane streets are not statistically or analytically different from the model developed from all study sections.

10. The engineer can use these mathematical models not only to predict a future driveway accident rate, but he also can use them to present facts defending his decisions to control the number of access points for the public well-being. Used within the constraints from which they were developed, the models can be valuable tools to all public officials concerned with the number of driveway accidents in their cities.

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